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Big data for low-carbon transport: an overview of applications for designing the future of road and air transport

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Abstract

Big data is one of the most promising research trends of this decade, and navigation data allows for unprecedented opportunities for designing future low-carbon transportation infrastructures. This paper presents two applications based on navigation data in the fields of road and air transport. The first application shows how driving patterns from conventional fuel vehicles can be used for developing real-world scenario analyses for deploying hybrid and electric vehicles, quantifying their energy demand on the electric grid and the infrastructure needed to serve it. Moreover, results of the real-world driving and non-driving emissions from conventional vehicles are also presented, adopting as example the Italian province of Firenze. The second application shows how flight pattern data can be combined with noise emission models to quantify the real-world noise impact of civil air operation. The computed sound levels allow for drawing real-world noise maps and three airports have been chosen as examples: a small aerodrome (Trieste), and two intercontinental hubs (Vienna Schwechat and London Heathrow).

Keywords: big data; low-carbon transport; navigation data; electric vehicles; noise maps; road transport; air transport;

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Nomenclature

ADS-B	Automatic Dependent Surveillance - Broadcast	GPS	Global Positioning System
ANP	Aircraft Noise and Performance	HDV	Heavy Duty Vehicles
ARP	Airport Reference Point	LDV	Light Duty Vehicles
BEV	Battery Electric Vehicle	PHEV	Plug-In Electric Vehicle
CO_2	Carbon Dioxide	POI	Points of Interest
ECAC	European Civil Aviation Conference	TEMA	Transport Technology and Mobility Assessment
EU	European Union	VOC	Volatile Organic Compounds

1. Transport figures in the European Union

In the European Union (EU), transport contributes to nearly one-third of the carbon dioxide (CO_2) emissions and is the only major sector where emissions increased over the last decade despite the economic downturn (European Commission Website, 2013). EU accounts of 35.3 billion tonnes CO_2-equivalent emissions in 2013 (European Commission Joint Research Centre, 2015), with approximately 11.6 billion tonnes coming from transport, of which 72% from road, 15% from rail and waterborne combined and 13% from air transport (European Commission, 2015). In this framework, the EU needs to strengthen its action for reducing Greenhouse Gases (GHGs) emissions by 20% below 1990 levels by 2020, and by 80-to-95% by 2050 as prescribed by the Kyoto Protocol (European Environment Agency (EEA), 2005), (United Nations Framework Convention on Climate Change, 2011), with transport contributing to this goal by reducing its GHGs emissions below 1990 levels by 60% by 2050 (European Commission, 2011). This is a priority to meet to global goal of keeping the increase in global average temperature at 1.5°C above pre-industrial levels, as per COP-21 Paris agreement (European Commission, 2016). Figure 1 depicts an overview of the main transport figures in the EU. Nearly two-thirds of road transport emissions originate from light duty vehicles (LDV), while the remaining one-third originates from heavy duty vehicles (HDV) (European Commission, 2015), representing respectively 83.3% of total inland surface passenger transport (LDV) and 9.2% of total inland surface passenger transport plus 74.9% of total inland surface freight transport (HDV). Rail transport accounts for 7.5% of total inland surface passenger transport and 18.2% of total inland surface freight transport, while waterborne accounts for the remaining 6.9% of the inland surface freight transport, with a passenger share that is negligible (Eurostat, 2015). By considering carbon-intensity per mode (i.e., CO_2 grams per kilogram of payload per kilometre), rail and waterborne are definitively greener solutions, accounting for nearly one-third of the specific emissions compared to road or air transport (European Environmental Agency, 2015). However, despite their carbon-reduction potential, rail and waterborne are still under-exploited solutions compared to road mode. Recent statistics show that the number of worldwide circulating vehicles is approximately 1.2 billion unit in 2014 (Greencarreport.com, 2014), exhibiting an annual growth rate of 4% until 2020 (McKinsey & Company, 2013). Such growth is mainly due to the increasing wealth in emerging countries (i.e., 76% of the 2020 automotive market is forecasted not to be in EU or US (McKinsey & Company , 2012)), with a long term growth up to 2.0 billion in 2035 (Greencarreport.com, 2014) and 2.4 billion circulating vehicles in 2050 (i.e., +100% compared to the 2014 figure, traded off by a worldwide population increase of 30% only (International Transportation Forum, 2014)). As far as air transport mode concerns, this is typically not included in road, waterborne and rail transport statistics, being natively cross-EU-borders and not "inland surface". As per road mode, air transport is also a carbon-intensive solution (their

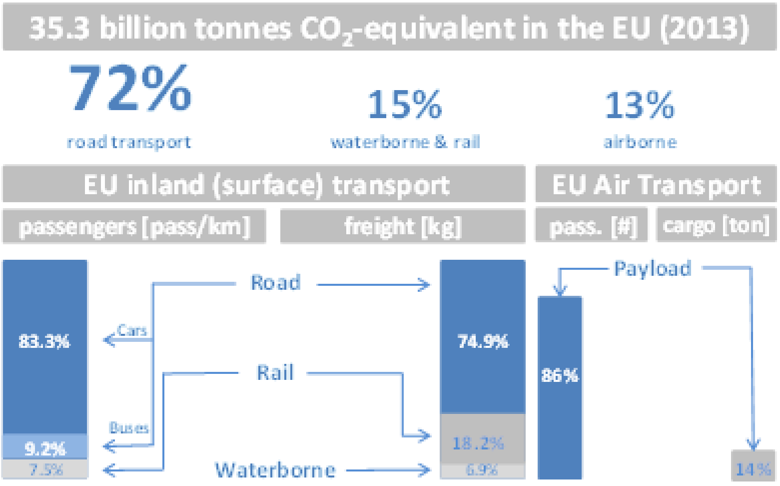

Figure 1. Summary of the main transport figures in the EU.

specific emissions are comparable) and fast growing. In fact air passengers in, from and to the EU went from 810 million in 2009 to 920 million in 2013 (+13.5% over 5 years, i.e., 86% of air-carried payload), while air cargo went from 11.8 million tonnes in 2009 to 15.0 million tonnes in 2013 (+27.1% over 5 years, i.e., 14% of air carried payload), as per (European Aviation Safety Agency, 2013). Air traffic is operated in the EU across approximately 450 airports, 150 airlines and 10 million scheduled flight per year, (EU Commission - DG Research and Innovation and DG Mobility and Transport, 2011), and it forecasted to grow by 2% per year until 2022, (Eurocontrol, 2016). Beyond air traffic congestion, this will impose significant environmental strains in terms of GHG emissions from air transport, combined with increased noise emission around airports.

Beyond the impact of GHG emissions on climate change, transport is also a significant source of noxious air pollutants that are proven to have serious implications on human health. The World Health Organisation highlights that tens of thousands of deaths per year can be attributed to transport-related air pollution, similar to the death toll from traffic accidents (Krzyzanowsk, Kuna-Dibbert, & Schneider, 2005), with evidences of a causal relationship between human exposure to traffic-related gaseous emissions and exacerbation of respiratory and cardiovascular diseases (Health Effects Institute, 2010). In this complex framework, the EC White Paper on Transport 2011 sets the de-carbonisation of transport as a priority, defining ten goals to be achieved in the next twenty to forty years (European Commission, 2011). These target a massive reductions of GHG emissions from the entire transport sector in Europe by enabling the transition from conventional fuel to electric cars in urban areas (objective 1), adopting low-carbon and alternative fuel solution in aviation and waterborne transport (objective 2), shift freight transport from road to rail and waterborne (objective 3), establishing an European framework for multi-modal transport supported by an adequate ICT backbone (objectives 4,5,6,7 and 8), moving towards safer road transport (objective 9) and toward "user/polluter-pays" taxation principles (objective 10). These objectives need to be sustained by adequate policy actions, and policy makers need a new generation of tools and methodologies to derive the effects of policy actions and of the deployment of new technologies for maximising the beneficial impacts of allocated resources.

This paper aims at providing the scientific community with two concrete examples of how big data can contribute in this respect. The first example consists in TEMA (Transport Technology and Mobility Assessment), that is a software platform developed at the Joint Research Centre of the EU Commission for simulating the effects of deploying electrified vehicle technologies, i.e., PHEV and BEV, at a regional level. The second example consists in a software application, developed in cooperation between the Austrian Institute of Technology GmbH and the University of Udine (Italy), which reconstructs flight patterns from web data and computes the noise exposure levels around European airports due to civil air traffic. Both applications, although at a different maturity level, demonstrate the huge potential of big data in designing the next generation transportation systems, accounting for environmental and economic aspects, and suggesting locally tailored solutions for road and air transport.

2. Use of big data in transport

The amount of data that modern digital devices can produce is staggering (Kaisler, Armour, Espinosa, & Money, 2013), and recent estimates suggest that 5 Exabytes of data (1 Exabyte = 10^6 Terabyte) are produced worldwide every second day (Jones, 2014). The era of information technology has enabled us to not only collect and store such amount of data, but it has also dramatically increased our ability to process it. However, it is not clear how data can, in real-world, affect our daily life, despite the fact that there is an increasing consensus of the scientific community on the fact that big data can provide unprecedented insights with applications in almost every field. A specific investigation on the potential impact of big data for governmental institutions has been carried out by McKinsey & Co, which indicates data mining as a significant opportunity to boost the efficiency and the value for money of public investments. This study quantifies that an effective use of big data in the European public sector administration might create value for approximately 250 billion € per year, i.e., approximately 2% of the EU nominal GDP (Gross Domestic Product) in 2015, leveraging EU annual productivity growth of 0.5% up to 2020 (McKinsey & Company, 2011). As far as transport is concerned, this is a complex and interdisciplinary research field, which mixes technological aspects, social behaviours, choices of single users and stochastic events. This complexity is nested within a geographical scenario (i.e., terrain profile and infrastructural networks), an environmental scenario (i.e., thermal and solar radiation conditions) and an economic and social scenario (i.e., regional/national wealth and social background). The effective design of the transportation network and its regulatory framework in a region involves expertise from engineering, geography, environmental sciences, economy and social sciences, and it must be supported by harmonised datasets from multiple sources combined with data processing methodologies developed across different scientific fields in order to handle real-world complexity. However, such data is often hard to retrieve and process with standard approaches focusing on partial datasets, single applications, pilot studies and statistical analyses. One possibility to overcome this limitation consists in relying on the data collection capabilities of current and future digital devices. Modern transport industry is, in fact, characterised by data production; every vehicle, either passenger car, truck, ship, train or airplane, is, or soon will be, constantly connected with navigation, data storage and data transmission systems. This data, possibly harmonised with data from smartphones and wearable devices, enable the full reconstruction in time and space of the movement of the people, allowing for unprecedented insights that can be used for assessing the environmental performance of vehicles, evaluate the utility of a transportation systems, conceive and design new transportation infrastructures, as well as simulate the effectiveness of new vehicle technologies under real-world operation.

3. Road transport application: the TEMA platform

TEMA is a flexible and modular big data platform, capable of processing large-scale databases of real-world driving patterns from GPS navigation systems of vehicles. TEMA's virtual environment allows for simulating in full detail the sensitivity of real-world mobility to different technological, societal and policy constraints. The platform natively operates at a regional level (i.e., NUTS-2), and relies on navigation datasets from conventional fuel vehicles. TEMA has been used so far in a number of applications, including:

- large scale statistical analyses from mobility data and inter-modality potential in urban areas (De Gennaro, Paffumi, Martini, & Scholz, A pilot study to address the travel behaviour and the usability of electric vehicles in two Italian provinces, 2014);
- estimation of the real-world potential of deploying urban hybrid and electric vehicles (Paffumi, De Gennaro, Scholz, & G, 2014), and their impact of the electric energy distribution grid at a regional level, including synergies with renewables (De Gennaro, Paffumi, Scholz, & Martini, 2014), (Chaouachi, et al., 2016) and V2G (Paffumi, De Gennaro, & Martini, Innovative technologies for smart cities: towards customer driven infrastructure design for large scale deployment of electric vehicles and Vehicle-to-Grid applications, 2016);
- smart design of alternative fuel infrastructure (De Gennaro, Paffumi, & Martini, Customer-driven design of the recharge infrastructure and Vehicle-to-Grid in urban areas: A large-scale application for electric vehicles deployment, 2015), in support to the European Commission communication on clean power for transport (European Commission, 2014), and to the proposal for a directive on alternative fuel infrastructure (European Commission, 2015) approved on October 22nd 2014 (Directive 2014/94/EU (European Parliament, 2014));
- quantification of the effectiveness of evaporative emissions control system under real-world constraints (Martini, Paffumi, De Gennaro, & Mellios, 2014), (De Gennaro, Paffumi, & Martini, Data-driven analysis of the effectiveness of evaporative emissions control systems of passenger cars in real-world use condition, 2016), in support to the revision of the article 4 of the EU regulation (EC) No. 715/2007 (European Parliament, 2007), according to the communication 2008/C (European Parliament, 2008).

Recently the platform has been extended with a battery ageing module for Li-Ion batteries, for predicting the in-vehicle performance degradation of automotive batteries for BEV and PHEV applications (a work carried out in frame of the UN/ECE Electric Vehicle and Environment Informal Working Group, Part B of the mandate (United Nations, Economic and Social Council , 2016)).

A comprehensive overview of TEMA with applications and results is provided in (De Gennaro, Paffumi, & Martini, Big Data for Supporting Low-Carbon Road Transport Policies in Europe: Applications, Challenges and Opportunities, 2016). The input data of TEMA consists in driving patterns from conventional fuel vehicles acquired via GPS records. Data acquisition campaigns are conducted on regional scale, and, at the present, the EU Commission JRC owns sixteen databases for the provinces of Modena and Firenze (IT), Amsterdam (NL), Brussels (BE), Paris (FR), Athens (GR), Lisbon (PT), Krefel (DE), Luxemburg (LU), Warsaw (PL), Bratislava (SK), Vienna (AT), Ljubljana (SI), Zagreb (HR), Budapest (HU) and Sofia (BG). In total, the data includes 632,186 vehicles, equivalent to 139.57 million km reconstructed with 2.57 billion records. The data from each database vary in fleet composition, frequency of acquisition, vehicles monitored and time period. Six out of the sixteen databases mostly include LDVs including 508,607 vehicles (80.4% of the total vehicles) with 1.78 billion GPS records (69.3% of the total records), equivalent to 9.08 million trips and parking events, for a total driving distance of 106.11 million km (76.0% of the total km). The results discussed hereunder aims at providing an overview of the capabilities of TEMA, and only refer to the database from the Italian province of Firenze. A first result consists in the urban mobility statistics; it is shown that the share of the fleet that is in motion at the same time never exceeds 10.4%, with a mean value of 4.47%.

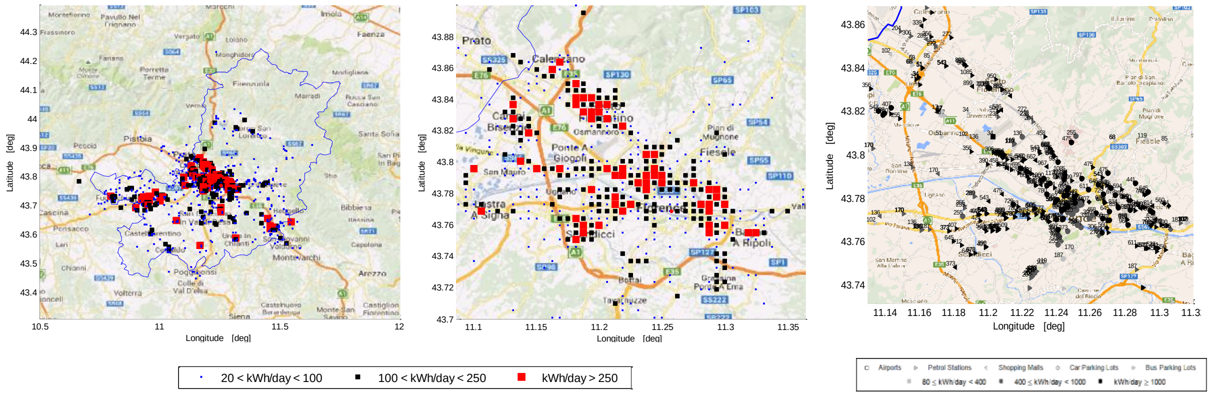

Figure 2. Extract from the geo-referenced energy demand results, province of Firenze, whole province area (left, blue line indicates the province border) and zoom on the city area (mid). Extract from the geo-referenced customer driven infrastructure results, province of Firenze, zoom on the city area (right). These results refer to a medium-sized BEVs (i.e. battery size of 24.0 [kWh] and averaged energy consumption of 210 [Wh/km]) coupled with a smart recharge strategy (i.e. recharge allowed only in a time window of 4 hours, i.e. ± 2 hours, around the minimum of the electric energy demand, at the power of 2 [kW]), referring to a conventional fuel o BEV fleet shift of nearly 20%. The results are reported in integral form in (De Gennaro, Paffumi, Scholz, & Martini, 2014) and (De Gennaro, Paffumi, & Martini, Customer-driven design of the recharge infrastructure and Vehicle-to-Grid in urban areas: A large-scale application for electric vehicles deployment, 2015).

By averaging the data on a weekly-basis, the averaged parked fleet share is most of the time above 90%, reaching a value above 99% from 1.00 and 5.00 in the morning, when almost all the vehicles are parked. Results also show that the time-averaged trip has a length between 5 and 20 km, a trip duration between 10 and 20 minutes, a trip speed between 25 and 40 km/h and parking duration between 2 and 12 hours, daily and nightly values respectively. By looking at the cumulative and probability distribution results approximately 50% of the trips have a driving length below 3.5 km, a duration below 8 minutes and an average speed below 25 km/h, while 90% of the trips are below 20 km, lasting less than 30 minutes, with an average speed below 50 km/h, with very similar results for both provinces. As far as parking duration is concerned, 50% of the parking events lasts less than 50 minutes (i.e., suitable for quick recharges), and 90% of the events take less than 700 minutes (~ 11.5 hours). Additionally, half of the vehicles in the sample make less than 6 trips and 20 km/day and 30 trips and 200 km/week, being parked for more than 90% of the time. Approximately 78% of the vehicles in the sample travel up to 50 km/day and approximately 9% of the vehicles in the sample exceed 100 km/day, reducing to 3% exceeding 150 km/day. The practical implication of these results is that approximately 7 out of 10 among the urban vehicles exhibit a predominant urban usage pattern and never show a trip length above 100 km, a value compatible with the driving range of most of the BEVs available on the market, implying that they can be targeted for early adoption of BEVs.

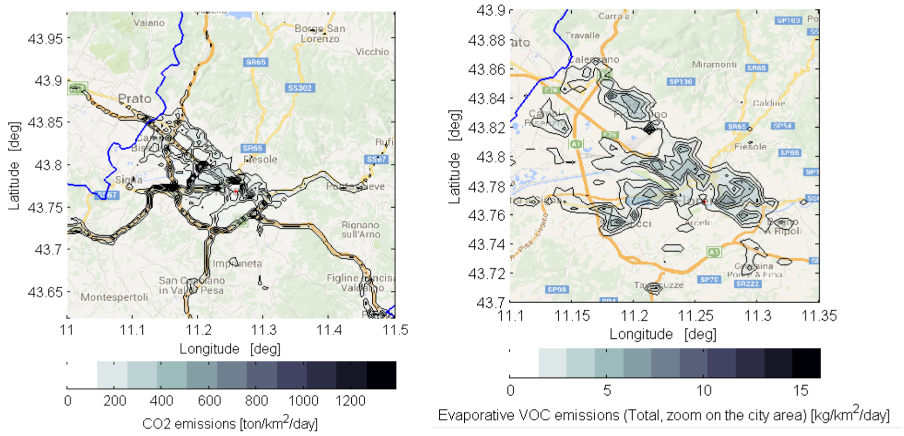

Figure 3. Geo-referenced CO_2 real-world driving emissions for province of Firenze (left). The results are calculated from the fuel consumption records of the year 2008 (Unione Petrolifera, 2016) and emission factors from (European Enviromental Agency, EEA, 2007), (European Commission, 1998) estimating 162.8 grams/km in the province of Firenze. Extract from the geo-referenced evaporative VOCs emissions results, province of Firenze (right), zoom on the city area. The results are derived by considering the worst emission scenario, i.e. month of July, tank headspace volume of 40 litres, activated carbon mass of 100 grams and desorption flow rate of 100 litres/hour, i.e. scenario 28 according to results reported in (De Gennaro, Paffumi, & Martini, Data-driven analysis of the effectiveness of evaporative emissions control systems of passenger, 2016).

By considering a small-to-medium sized BEVs (battery size between 16.0 and 24.0 kWh and energy consumption between 180 and 210 Wh/km), regardless of the recharging strategy, the vast majority of the trips of the database, i.e. more than 80%, can be driven electric. This is a result derived at a fleet level, that is by considering the trips of the fleet as non-correlated events, whereas by looking at the results at a vehicle level, approximately 10% to 25% of the fleet is capable to drive only electric, depending on the recharge strategy, meaning that the trip sequence of the vehicle is never interrupted by trip failure events. These results lead to two conclusions: (1) most of the real-world urban mobility demand can be served by BEVs, thus enabling a shift from conventional fuel vehicles to BEVs of about four-fifths of the urban mobility and (2) a non-negligible share of the fleet, i.e. approximately one-fifth, would not suffer any range limitation as consequence of this shift. Based on these results, the electric energy demand in time and space from different shares of BEVs in the real-world mobility can be derived. By assuming the small-to-medium sized BEVs as above and by shifting a fleet share going from 10-to-25% from conventional fuel vehicles to BEVs, an electric energy demand increase on the province from 0.4% to 5.1% is generated.

Figure 2 (left and mid pictures) depicts an extract from the geo-referenced energy demand results for the province of Firenze. In this picture three ranges of energy demand have been assumed, i.e., averaged daily energy demand between 20 and 100 kWh, between 100 and 250 kWh and above 250 kWh, each of them associated to a terrain tile of 500 x 500 meters. These has been depicted by using small-sized black squares, medium-sized blue squares and big-sized red squares, respectively. Figure 2 (right pictures) depicts the infrastructure needed to serve this demand, as calculated by a demand-offer matching algorithm, which distribute the calculated energy demand over a database of suitable locations for installing charging columns (Points of Interest, POI). Each POI is hence characterized by a local daily energy demand, the number of charging column needed in that specific location, the Geographic Key Performance Indicator (Geo_{KPI}), representative of the capability of a specific POI to be as close as possible to the demand, and the Repetitiveness index (R), representative of the rate of occurrence of the recharges of the same vehicle at the same POIs, characterizing the potential customers as recurring or occasional customers. This methodology allows for detailed design of a recharge infrastructure in a region tailored on real-world user demand. Figure 3 depicts an example of geo-mapping of driving and evaporative emission estimation from passenger cars. The picture on the left hand side depicts the CO_2 emission sources in tons per km^2 per day from the urban fleet in Firenze, by considering the yearly fuel consumption statistics in Italy for each fuel type (Unione Petrolifera, 2016) and the emission factors as per (European Enviromental Agency, EEA, 2007). The calculated average CO_2 emissions in grams/km for each vehicle are then scaled up to the province fleet size, referring only to the passenger cars (both gasoline and diesel), as per vehicles contained in the databases. The simplified assessment only refers to LDVs, thus not considering heavy duty vehicles, buses, mopeds and motorcycles. Applying this methodology for the year 2008, a weighted passenger cars fleet emission factor of CO_2 equal to 162.8 grams/km for the province of Firenze is derived. The picture on the right hand side depicts instead the evaporative VOC emission sources in kg per km2 per day from the urban passenger cars in Firenze, by considering the worst emission scenario, i.e., month of July, tank headspace volume of 40 litres, activated carbon mass of 100 grams and desorption flow rate of 100 litres/hour. This is part of a complete scenario analysis reported in (De Gennaro, Paffumi, & Martini, Data-driven analysis of the effectiveness of evaporative emissions control systems of passenger, 2016).

4. Air transport application: web data collection for computing real-world noise levels around airports

In order to promote the growth and sustainability of the air transport market, the European aeronautic industry aims at reducing by 75% the CO_2 emission, by 90% the NO_x emission and by 65% the perceived noise compared to a new average aircraft delivered in the year 2000 by 2050 (EU Commission - DG Research and Innovation and DG Mobility and Transport, 2011). In this timespan, the industry will be pivoted around the concept of narrow-body airliners with capacity up to 300 seats (e.g. A320 and B737) for operation on short haul (below 3,000 nautical miles). Therefore, the efforts in research and development will be streamed towards delivering more efficient and cleaner propulsion technologies (i.e. ultra-high bypass engines, geared turbofans, open rotors and CRORs), weight reduction by massive adoption of advanced composites, combined with low-drag aerodynamic solutions (i.e. natural/artificial laminar wing) and enhanced operation by increased load factors and better Air Traffic Management (ATM). Concerning noise, the efforts will focus on minimizing airframe noise (slats, flaps, spoilers, landing gear noise) and propulsion noise (fan, compressor, turbine and jet noise, impact of propellers and reverse thrust), together with better management of take-off, landing and taxing flight phases. In such context, ICAO adopted countermeasures since 1970s, imposing noise standards and increasing their stringency alongside aviation technical developments (Dickson, 2013). While these rules have contributed to reducing noise levels around airports (Astley, 2014), the increase in the number of flights is deemed to be an important cause of disturbance for people living close to runways (Lawton & Fujiwara, 2016). In recent years, the fast growth of the Internet and the widespread installation of ADS-B transponders on air vehicles have led to the birth of websites called "flight trackers" aimed at providing the public with aircraft movement data in real time. Examples of such flight trackers are Flightradar24 (Flightradar24, 2017), FlightAware (FlightAware, 2017) and Plane Finder (Plane Finder, 2017), which collect data from thousands of ADS-B receivers located all over the world and from other surveillance devices based on multilateration and radar technologies. In the present work, web data of flight paths and aerial vehicles have been used together with the ANP database (Eurocontrol Experimental Centre, 2017) as a source of information for the ECAC best-practice noise model (European Civil Aviation Conference, 2005), which allowed the computation of contour maps of the aircraft noise levels around European civil airports. Generally, flight trackers offer very rich data, such as airplane position, speed, course and height, with a time resolution up to 15 seconds, but they do not always provide information on aircraft models, and hence on type, number, and position of engines, which is essential for aircraft noise computation. To overcome this issue, other websites can be consulted, for example aircraft model database Airfleets (Airfleets, 2017). The first step of the present study was to collect web data concerning flights arriving at and departing from airports. These data were then enriched with aircraft details retrieved from aircraft model databases. A total of 2,300 airports throughout the Eurocontrol territory and in some non-Eurocontrol countries (Israel, Palestinian territories, Gibraltar, Iceland and Azerbaijan) were considered, and data from 36,302 flights in a lapse of few days have been retrieved and stored in a flight database. To allow their use as an appropriate input to the ECAC noise model and ANP database a post-processing program was developed that: (1) translates each aircraft into the most similar model in the ANP database, (2) assigns to each flight a take-off or landing runway according to a specially developed algorithm (available flight path data usually start or end at some distance and altitude from the runways), (3) reconstructs dates and times of departures and arrivals according to the time zones, and (4) rearranges pieces of information in each file according to a standard data structure. After discarding a number of flights that lacked key data, the post-processing code was able to recover 34,818 flights, whose data were corrected, completed and reorganized before being stored in a database directly usable by the noise prediction model.

The ECAC best-practice noise model is based on four key features: ground tracks, procedural steps, a database with aircraft noise values, and a noise calculation engine. In general, the aircraft route is approximated by a 3-D segmented flight path, obtained by merging ground tracks and procedural steps, and the individual segments are used as the key input to the noise engine. Procedural steps, noise reference values and many noise engine parameters are found in the ANP database. A ground track is basically the 2-D projection of the aircraft route onto the ground surface. It is generated by using the collected flight data: for each flight operation of interest (departure or arrival), the aircraft positions on the ground surface (latitude and longitude) in the vicinity of the airport are interpolated with straight lines and circular arcs, and the resulting track is split into a variable number of segments. With ground track segments available, procedural steps - and when non-existent, fixed-point profiles - are used to calculate the height, speed and engine thrust/power of the aircraft along the ground track. These steps are performed sequentially, generating a segmented 3-D flight path and providing the aircraft bank angles along the curved trajectories. According to the ECAC noise model, the global sound level at the receiver position is evaluated by superposing the effects of the individual flight path segments. The contribution of each segment is computed taking into account the relative position of the segment and receiver and some aircraft parameters, such as the bank angle. The baseline noise level produced by each segment is computed as a function of the receiver-segment distance and engine power setting by using the Noise-Power-Distance – NPD – tables (European Civil Aviation Conference, 2005). Then, it is corrected by the contributions of lateral directivity, ground speed, position of engines and runway-related events such as reverse thrust. Moreover, in case exposure levels are being calculated, a finite segment correction is applied to account for the fraction of the total sound energy that reaches the receiver. Ultimately, for every aircraft operation at a given airport and each receiver position, two A-weighted sound levels are calculated, i.e., a maximum level ($L_{A,max}$) and a sound exposure level (SEL). These sound levels can be used in a number of cumulative metrics aimed at representing the overall effect of flight events within certain time spans. In the present work, the "Day-Evening-Night average sound level" (L_{DEN}) was considered. It accounts for exposure levels during 24 hours, and penalizes the flight operations that take place in the evening and at night, when people are assumed to be more annoyed by aircraft noise, by adding 5 dB(A) and 10 dB(A), respectively, to the actual exposure level. The noise computation program developed on the basis of the ECAC model is able to calculate cumulative noise levels around airports in a full day (in the present work, October 12th 2016 was considered as example).

The program performs the following tasks: (1) take a flight operation (departure or arrival) from the flight database, (2) check if the flight operation occurred on the desired day and information is sufficient for the noise computation, (3) if positive, calculate the sound level at all the receiver positions, and (4) repeat the process for all flights. Around every airport, a square surface area with each edge equal to 162,000 ft centred at the ARP and a square array of receivers with 1,500 ft spacing were considered, which translates to 11,881 receivers in about 2,440 km^2. As a first approximation, all receivers were assigned the ARP elevation. When executed, the computer program was able to recognize and manage:

- 391 airports out of 2,300 with at least one flight operation;
- 65,182 total flight operations;
- 30,660 assessed flight operations in the selected day, namely, 14,433 departures and 16,227 arrivals.

The difference between the number of departures and arrivals is mainly due to a simplification introduced in the data collecting procedure, which has been limited to the arrivals. Therefore, continental departures can be retrieved by consulting the flight history of landed aircraft, but intercontinental ones cannot. It was estimated that around 32,500 flight events per day took place throughout the Eurocontrol territory in October 2016 (STATFOR, 2016). Considering that only 151 flight operations out of 30,660 total events were detected in non-Eurocontrol countries, the present procedure led to retrieve about 94% of the daily average of flight operations. However, the percentage of recovered data changes significantly from small/medium to large airports. Figure 4 shows the computed L_{DEN} contour maps around the airports of Trieste (Italy), and Vienna-Schwechat (Austria). The first one is a small aerodrome, without intercontinental flights, where the number of assessed operations (12 departures and 11 arrivals) is in line with the daily average air traffic recorded in 2016 and 2017 (Trieste Airport - Friuli Venezia

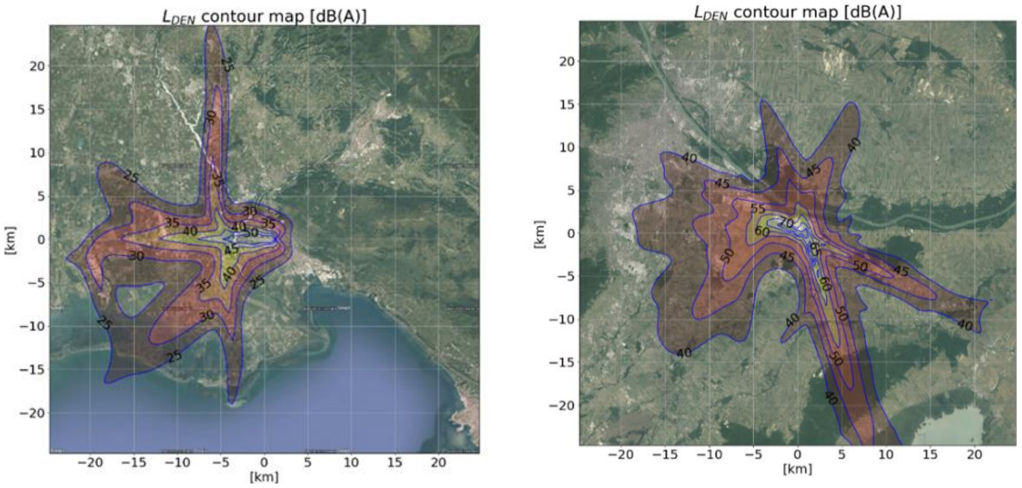

Figure 4. Computed L_{DEN} contour maps at Trieste Airport (left) and Vienna-Schwechat (right) on October 12th, 2016. Sound levels are much higher, on average by 20 dB(A), in the area of Vienna airport, where the total number of flight operations is more than one order of magnitude higher than in Trieste Airport.

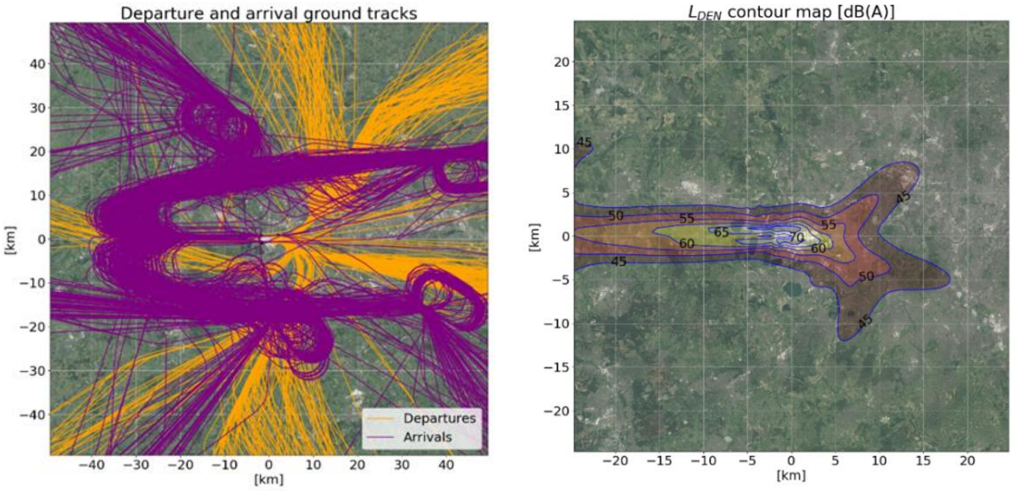

Figure 5. Computed ground tracks for departures and arrivals at Heathrow Airport (left) and contour map of L_{DEN} from 45 to 70 dB(A) (right) on October 12th, 2016. In the plot of ground tracks, the distances from the ARP are doubled in both directions to provide a broader view of the major aircraft routes.

Giulia, 2017). On the contrary, only 583 events (281 departures and 302 arrivals) were assessed for the larger airport of Vienna, which accounted for an average of 651 flight operations per day in October 2016 (Vienna International Airport, 2017). This difference can be partially explained with the lack of data on intercontinental departures, the number of which was found to be usually less than the non-retrieved data in large airports. Therefore, it is likely that part of the missing operations are due to cargo and general aviation flights, which remains unrecorded. Figure 5 shows instead the results obtained for the airport of London Heathrow (UK), where an average number of 1,293 operations per day took place in 2016 (Heathrow Airport, 2017). On the left side is the ground track distribution of 410 departures and 605 arrivals (1,015 events retrieved, that is 78.5% of the average number of daily operations), and on the right is the corresponding L_{DEN} contour map, whose shape matches quite well the flight distribution. Heathrow represents an extreme case, being one of the largest airports in the world, and the large number of intercontinental flights together with missing or defective information from ADS-B data causes the total number of retrieved flight operations to be significantly less than the expected one. The present computation, parallelized by splitting the airports into a number of input lists, took about 5 days using 13 cores of a cluster node, one for each airport list.

5. Concluding remarks

This paper presents an overview of the results from both previous and new studies of the authors on the use of big data in transport. The work includes both road transport results, presenting the TEMA platform, as well as air transport results, presenting the early results of an application that combines flight data from web with standard noise emission models. The authors want to remark the huge informational potential contained in the data and the nearly unlimited possibilities offered by the presented approaches for quantifying real-world effects of transport systems and technologies on the society and economy. On the other side, it is important to highlight the huge efforts needed to collect, clean and make the data suitable to be processed, as well as the necessary expertise for managing and effectively processing the data. Standardised approaches in future might facilitate and speed up data collection and processing practices (e.g. future applications in the field of autonomous driving systems might do so), although standard processes might also incur in the risk of limiting its benefits, preventing possible exploitation paths. However, the meaningfulness of the analyses presented and the flexibility offered by big data pave the way to data mining to play a major role in the research landscape of the next decade. Transport research is at a turning point: the technology is now mature for exploiting data potential in shaping the future of low-carbon mobility, and big data has the potential of revolutionising the decision-making process in the field of transport.

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